

UNITED STATES AIR FORCE RESEARCH LABORATORY

Helmet Pointing Performance Differences between Males and Females During High-Sustained Acceleration

Nasser H. Al-Nuaimi

WRIGHT STATE UNIVERSITY
3640 Colonel Glenn Highway
Dayton OH 45324

Edward S. Eveland

AIR FORCE RESEARCH LABORATORY

Chuck Goodyear

STATISTICAL CONSULTANTS, INC.
Waynesville OH 45068

August 2000

Interim Report for the Period November 1999 to July 2000

20020913 001

Approved for public release; distribution is unlimited.

Human Effectiveness Directorate
Biodynamics and Protection Division
Biodynamics and Acceleration Branch
2800 Q Street
Wright-Patterson AFB OH 45433-7947

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Air Force Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
8725 John J. Kingman Rd., Ste 0944
Ft. Belvoir VA 22060-6218

TECHNICAL REVIEW AND APPROVAL


AFRL-HE-WP-TR-2002-0138

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR


F. WESLEY BAUMGARDNER, PhD
Chief, Biodynamics and Protection Division
Air Force Research Laboratory

| | | | | |
|--|---|---|---|--|
| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | |
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503 | | | | |
| 1. AGENCY USE ONLY (Leave Blank) | | 2. REPORT DATE August 2000 | 3. REPORT TYPE AND DATES COVERED Interim Report - November 1999 thru July 2000 | |
| 4. TITLE AND SUBTITLE Helmet Pointing Performance Differences between Males and Females During High-Sustained Acceleration | | | 5. FUNDING NUMBERS PE: 62202F PR: 7184 TA: 45 WU: 01 | |
| 6. AUTHOR(S) Nasser H. Al-Nuaimi*, Edward S. Eveland**, and Chuck Goodyear*** | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) *Wright State University 3640 Colonel Glenn Highway Dayton OH 45324 ***Statistical Consultants, Inc. Waynesville OH 45068 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory, Human Effectiveness Directorate Biodynamics and Protection Division Biodynamics and Acceleration Branch** Air Force Materiel Command Wright-Patterson AFB OH 45433-7947 | | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-HE-WP-TR-2002- 0138 | |
| 11. SUPPLEMENTARY NOTES | | | | |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited | | | 12b. DISTRIBUTION CODE | |
| 13. ABSTRACT (<i>Maximum 200 words</i>) Because females only recently became fighter pilots, the literature contains very little information on female performance during high-sustained acceleration. The hypothesis of this research was that female subjects would have similar helmet pointing task performance during high-sustained acceleration compared to males. Five female and five male subjects performed simple and complex tracking tasks at 1.4, 4.0, and 6.5 Gz in a human centrifuge. There was no significant difference in helmet pointing performance between males and females under the different gravity (G) settings. Overall, male subjects performed 17% better but this difference was not statistically significant. Means followed trends where increasing helmet weight or a movement in the center of gravity away from a reference position resulted in poorer tracking performance; however, the mean differences were very small compared to the effects of task and Gz. | | | | |
| 14. SUBJECT TERMS high G, helmet mounted displays, helmet biodynamics, gender differences, helmet sight, dynamic tracking performance | | | 15. NUMBER OF PAGES 18 | |
| | | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED | 18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED | 19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED | 20. LIMITATION OF ABSTRACT UNLIMITED | |

THIS PAGE LEFT BLANK INTENTIONALLY

PREFACE

This research was performed in conjunction with an Air Force Research Laboratory (AFRL) helmet biodynamics research project at AFRL/HEPA, Bldg 33. The project was partially funded by the Joint Strike Fighter Systems Program Office at Wright-Patterson AFB OH.

The AFRL Human Effectiveness Directorate has a memorandum of agreement with Wright State University (WSU) to "pursue common research and education goals through cooperative and supportive efforts." Aerospace medicine residents at WSU conduct research in the directorate as partial fulfillment of the MS degree in Aerospace Medicine.

Dr. Al-Nuaimi was a graduate student and completed this thesis research as a partial fulfillment of the MS in Aerospace Medicine degree at Wright State University in 2000.

Additional subject data were collected and analyzed after Dr. Al-Nuaimi completed the report for his MS degree. This technical report has been changed to reflect the findings from those data.

THIS PAGE LEFT BLANK INTENTIONALLY

TABLE OF CONTENTS

| | Page |
|---------------------------|------|
| PREFACE..... | iii |
| INTRODUCTION..... | 1 |
| MATERIAL AND METHODS..... | 1 |
| Subjects..... | 1 |
| Centrifuge..... | 2 |
| Study Design..... | 3 |
| RESULTS..... | 6 |
| DISCUSSION..... | 9 |
| CONCLUSION..... | 10 |
| REFERENCES..... | 11 |

LIST OF FIGURES

| Figure | Page |
|--|------|
| 1. Dynamic Environment Simulator (DES) Centrifuge..... | 3 |
| 2. Sample Run..... | 4 |
| 3. Back View of Subject Sitting in the DES Cab Performing the Helmet Pointing/Aiming Task..... | 4 |
| 4. Helmet Pointing Task on DES Cab Screen..... | 5 |
| 5. Variable Weight/Center-of-Gravity Research Helmet (Side and Front Views)..... | 5 |
| 6. Main Effect Means..... | 7 |
| 7. Individual Means at $G_z = 6.5$ | 8 |

LIST OF TABLES

| Table | Page |
|--|------|
| 1. Analysis of Variance (ANOVA) Results..... | 7 |

INTRODUCTION

As of recent times, very little information is known about female gravity (G) tolerance and performance in high-G environments. With female pilots now flying high-performance aircraft, in both the US Air Force and Navy, gender-specific factors that may affect female acceleration tolerance have become increasingly essential (1, 2, 3, 4, 6, 7, 8, 9, 11, 15, 16, 17, 20, 21). G-tolerance differs widely among individuals (males and females) (5, 10, 13, 14, 19). It stands to reason that aircrew with higher G-tolerance are less likely to experience symptoms of G-stress in flight than are those with lower G-tolerance, and that they can fly highly maneuverable aircraft with greater safety and effectiveness. To give surety that aircrew with abnormally low G-tolerance are not assigned to aircraft that function in the high-G environment, a G-tolerance standard and the means to execute that standard are crucial (10, 12).

Helmet-mounted systems (e.g., night vision goggles, missile aiming systems) are being introduced to the fighter cockpit. Helmets can now weigh 1 - 2.5 lbs. heavier with these systems (18). How will this added weight and change in the center of gravity (CG) of the helmet affect pilot performance? How will females perform in this environment when, in general, it is believed they have weaker neck muscles than their male counterparts?

The neck musculoskeletal system must bear increased loads with the addition of weights on the helmet. These loads were expected to produce some minor muscular pain or soreness in some subjects. The symptoms should be alleviated within 24-48 hours, similar to what would be expected following weight-bearing exercise. The purpose of the study was to compare the genders in their ability to perform a helmet pointing task at high G.

MATERIAL AND METHODS

Subjects

Ten subjects (five females and five males) were included in this study. The average age of the female subjects was 26.6 years (range = 22-32), their average weight was 59.4 kg (range = 52.2-66.2), and their average height was 162.6 cm (range = 157.5-177.8). The average age for the male subjects was 30.2 years (range = 26-36), their average weight was 70.9 kg (range = 57.6-79.3), and their average height was 169.4 cm (range = 157.5-177.8). All

subjects tested were members of the Air Force Research Laboratory (AFRL) Sustained Acceleration Panel of Wright-Patterson Air Force Base (WPAFB), Ohio.

The Institutional Review Boards of Wright State University (WSU) and AFRL approved the research protocol of this study, which is part of the AFRL helmet study. According to guidelines established by both the AFRL and WSU and prior to participation in this study, all subjects were briefed on the research protocol, including the potential risks, and then their informed consent was collected. Each subject passed the medical screening examinations including: spinal and cranial radiographs, blood analysis, electrocardiogram (ECG), and a neurological exam. Subjects were protected by the appropriate G-suits necessary for the G-level of the trial. They were trained to experience multiple G-exposures and were provided by verbal feedback of their physical and visual status throughout the profiles.

Centrifuge

The Dynamic Environment Simulator (DES), located at the AFRL, was used to produce the sustained acceleration environment for the study. The DES, a 19-foot radius man-rated centrifuge, has the capability of precision three-axis motion and can simulate any of the three G-vectors independently or combined in either open- or closed-looped mode (Figure 1). Subjects were seated in the gondola with the seat, ACES II-type, configured with a 15-degree seat back, facing forward with adequate restraint belts for positive sustained acceleration. The DES arm speed and cab position was operated under open-loop computer control with hypergravity experiences in the +Gz axis.

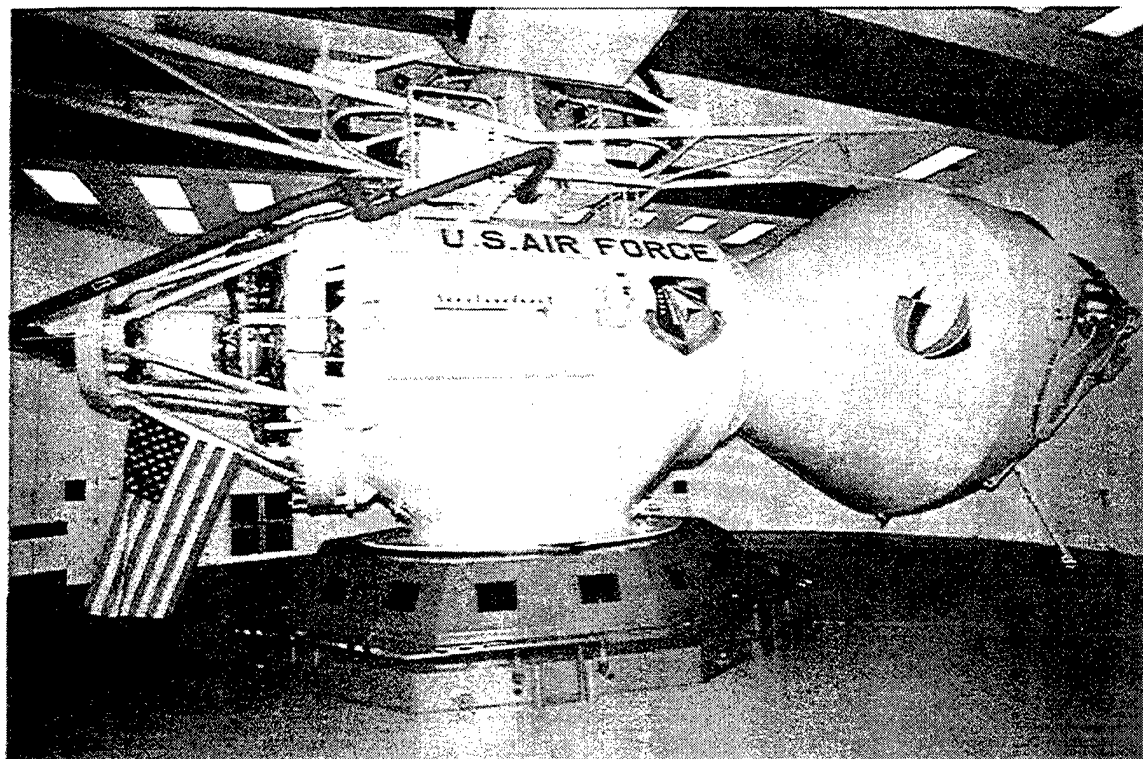


Figure 1. Dynamic Environment Simulator (DES) Centrifuge

This experimental configuration was similar to the one used in evaluation of the Interim-Night Integrated Goggle Head Tracking Systems (I-NIGHTS) performed in the AFRL (18).

Study Design

The first phase of the study required a few G-exposures for training and familiarization before exposing the subjects to the range of accelerations used in the study. Subjects were placed in the cab of the DES centrifuge and exposed to a 1.4 Gz "baseline" condition (12 revolutions/minute) and a 6.5 Gz peak (30 revolutions/minute) Simulated Air Combat Maneuver (SACM). Each run was 6 minutes in duration including 2 minutes of pre baseline, 2 minutes of SACM, and 2 minutes at post baseline (Figure 2).

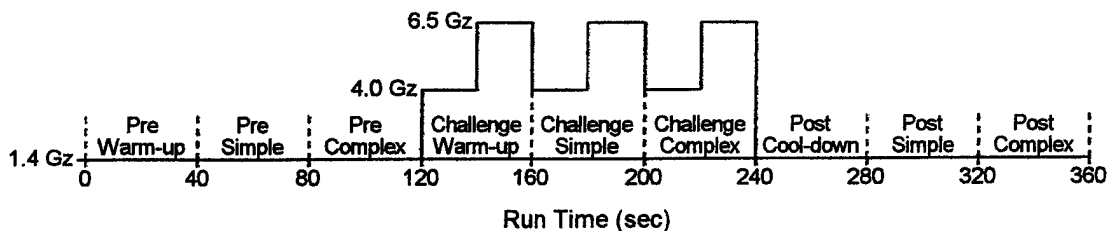


Figure 2. Sample Run

For the tracking task, a screen was mounted in front of the subject. A head-slaved tracking task was projected onto the screen to measure performance. A target (box in Fig. 4) was projected onto the screen in front of the subject to simulate the motion of an object outside and beyond the aircraft. The field-of-view for the tracking task was 56° H x 44° V (Figure 3). The task consisted of aiming the helmet-mounted laser pointer (circle) at the randomly moving box projected on the screen in the dark cab (Figure 4). Video capture tracking software was used to measure the pilot error during the tracking task. The helmet system, developed by the AFRL, allows for varying the system weight and CG (Figure 5).

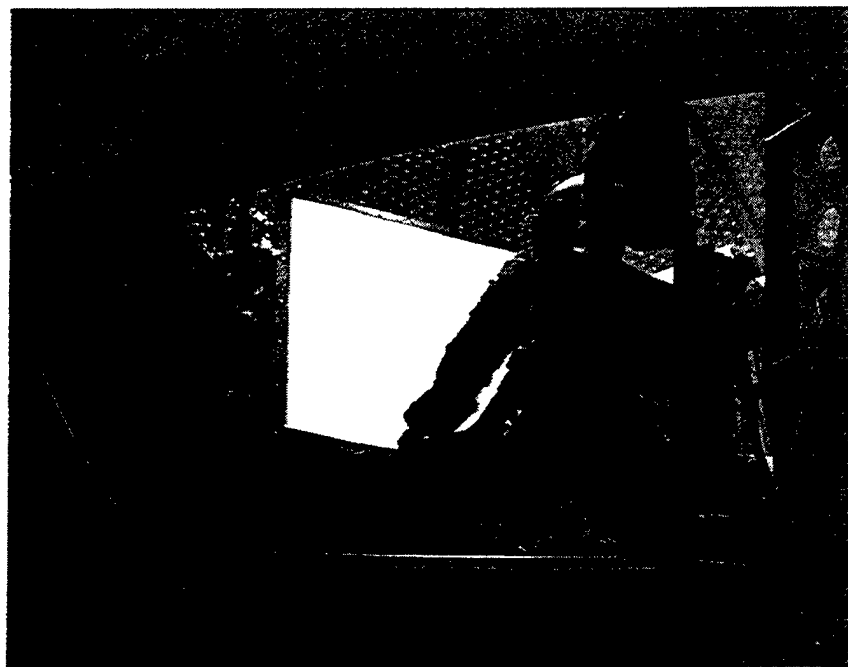


Figure 3. Back View of Subject Sitting in the DES Cab Performing the Helmet Pointing/Aiming Task

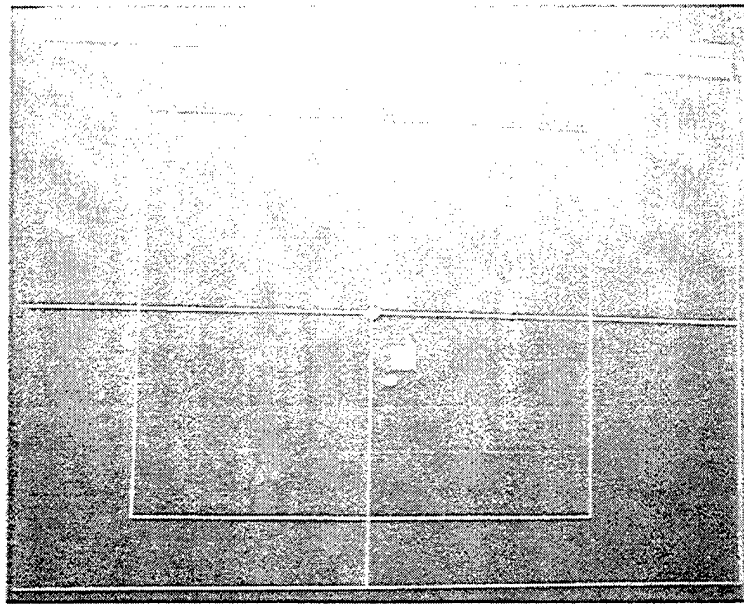


Figure 4. Helmet Pointing Task on DES Cab Screen

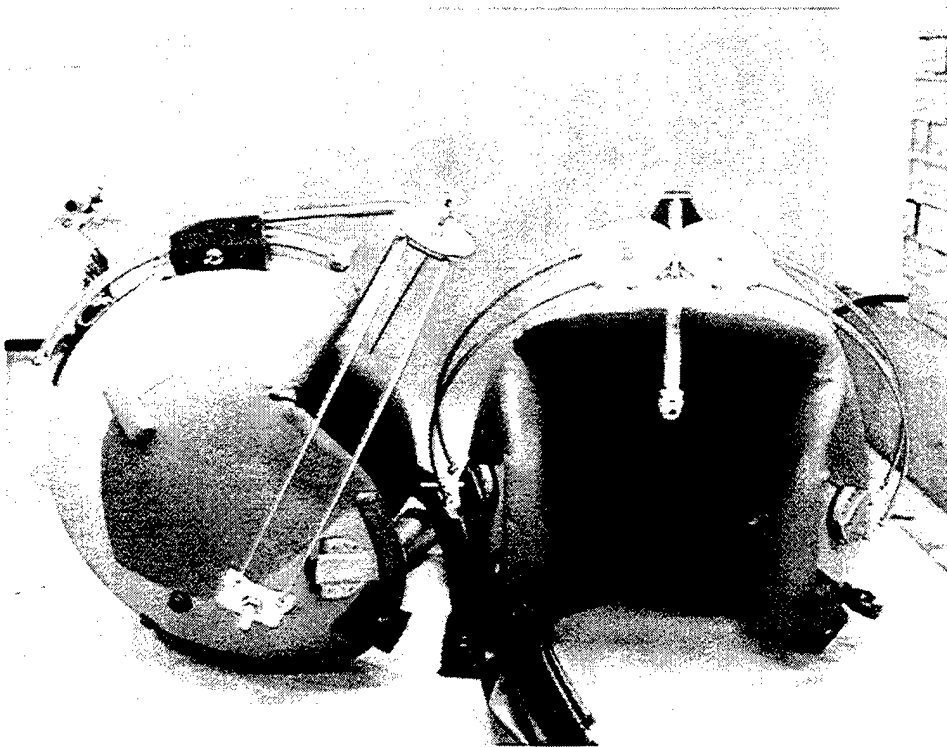


Figure 5. Variable Weight/Center-of-Gravity Research Helmet (Side and Front Views)

Helmet weight and CG was controlled using a set of weighted attachments to allow the CG to be adjusted by changing the position of attachments securely mounted on the side of the helmet. Two helmet configurations weighing 2.5 lbs. (no added weight) and 3.5 lbs. (1 lb. added) were used for testing (Figure 5). Adequate sizing to insure proper "fit" for all subjects was used. Experienced personnel were appointed to help insure the best fit of helmets for all subjects.

From the performance data, tracking error was calculated using root mean square error (RMSE). Statistical Analysis Software (SAS) was used to perform a mixed design analysis of variance (ANOVA). Post-hoc paired comparisons used the Bonferroni paired comparison procedure with a familywise error level of 0.05.

All on-site monitoring was conducted by a qualified flight surgeon, who evaluated every G-exposure. All subjects were clinically examined to ensure fitness both before and after each run.

RESULTS

Factors used in the analysis were gender (female, male), tracking task (simple, complex), Gz (1.4, 4.0, 6.5), and helmet (2.5-0, 3.5-0, 3.5-1). Helmet is a combination of helmet weight and CG where the number before the dash is the helmet weight in pounds and the number after the dash is CG in inches.

After the initial period of training, each subject had six experimental days with two runs per day. During a particular day, the subject would wear one of the two helmet weights for both runs. On days using the 3.5 lb. helmet, each CG (0 or 1) was used for one of the runs. The presentation of task and helmet were counterbalanced within each subject in order to help minimize order effects. During each test run, the subject would perform both tasks at pre baseline (1.4 Gz), at 4.0 and 6.5 Gz, and end with both tasks at post baseline (1.4 Gz).

The tracking RMSE was determined for each subject, day, run, Gz (pre and post separately), and task. The tracking RMSE values were logged for analysis due to positive skewness. The logged values were then averaged for each combination of subject, task, Gz (pre and post baseline combined), and helmet. Across days and runs, there were 16 replications at 1.4 Gz and 4 replications at 4.0 and 6.5 Gz. These averaged values were used as the dependent

variable in a mixed design ANOVA with gender (female and male) a between factor and within factors helmet (2.5-0, 3.5-0, 3.5-1), task (simple, complex), and Gz (1.4, 4.0, 6.5).

Table 1 presents the ANOVA results. The Greenhouse-Geisser corrections are given. The error term for the test of gender was subject nested in gender. For all other tests, appropriate subject interactions were used as the error term. Figure 6 contains main effect means.

Table 1. Analysis of Variance (ANOVA) Results. The Dependent Variable was Log (Tracking RMSE).

| Source | DF | SS | DFE | SSE | F-value | P-value | G-G P-value | G-G Epsilon |
|------------|----|----------|-----|----------|---------|---------|-------------|-------------|
| Gender (G) | 1 | 2.39E-01 | 8 | 1.30E+00 | 1.47 | 0.2599 | | |
| Helmet (H) | 2 | 1.23E-02 | 16 | 2.38E-02 | 4.15 | 0.0353 | 0.0403 | 0.9131 |
| Task (T) | 1 | 1.36E+00 | 8 | 1.61E-02 | 678.75 | 0.0001 | | |
| Gz (Gz) | 2 | 2.18E-01 | 16 | 1.79E-01 | 9.75 | 0.0017 | 0.0036 | 0.8222 |
| G*H | 2 | 5.75E-03 | 16 | 2.38E-02 | 1.94 | 0.1766 | 0.1814 | 0.9131 |
| G*T | 1 | 1.98E-04 | 8 | 1.61E-02 | 0.10 | 0.7614 | | |
| G*Gz | 2 | 4.10E-02 | 16 | 1.79E-01 | 1.84 | 0.1915 | 0.2001 | 0.8222 |
| H*T | 2 | 2.87E-03 | 16 | 1.72E-02 | 1.33 | 0.2919 | 0.2908 | 0.7842 |
| H*Gz | 4 | 7.23E-03 | 32 | 2.40E-02 | 2.41 | 0.0696 | 0.0941 | 0.7275 |
| T*Gz | 2 | 1.75E-02 | 16 | 1.36E-02 | 10.28 | 0.0013 | 0.0034 | 0.7901 |
| G*H*T | 2 | 4.29E-03 | 16 | 1.72E-02 | 1.99 | 0.1688 | 0.1811 | 0.7842 |
| G*H*Gz | 4 | 5.99E-03 | 32 | 2.40E-02 | 2.00 | 0.1184 | 0.1433 | 0.7275 |
| G*T*Gz | 2 | 2.74E-03 | 16 | 1.36E-02 | 1.61 | 0.2312 | 0.2372 | 0.7901 |
| H*T*Gz | 4 | 1.58E-03 | 32 | 2.09E-02 | 0.60 | 0.6630 | 0.6041 | 0.6785 |
| G*H*T*Gz | 4 | 1.86E-03 | 32 | 2.09E-02 | 0.71 | 0.5892 | 0.5417 | 0.6785 |

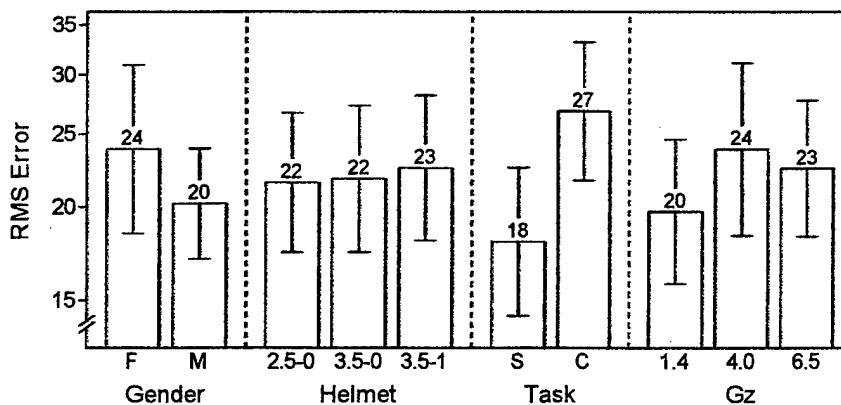


Figure 6. Main effect means \pm standard deviation of subjects

As seen in Table 1, there was not a significant main effect of gender ($p = 0.2599$) or any significant interactions with gender ($0.1433 < p$). There was a significant main effect of helmet ($p = 0.0403$) with post-hoc paired comparisons showing 2.5-0 significantly different from 3.5-1 and no other paired comparisons significant. There were also significant main effects of task ($p = 0.0001$) and Gz ($p = 0.0036$), however, there was also a significant interaction between task and Gz ($p = 0.0034$). Simple main effect tests and paired comparisons within the task*Gz interaction did not show mean differences in Gz with the complex task varying much compared with mean differences with the simple task. The significance of the interaction is more a result of very consistent mean differences across subjects.

Figure 7 shows the mean tracking error for each subject at Gz = 6.5. Since the primary purpose of this study was to examine genders under Gz stress, this figure indicates performance under the highest Gz in the study.

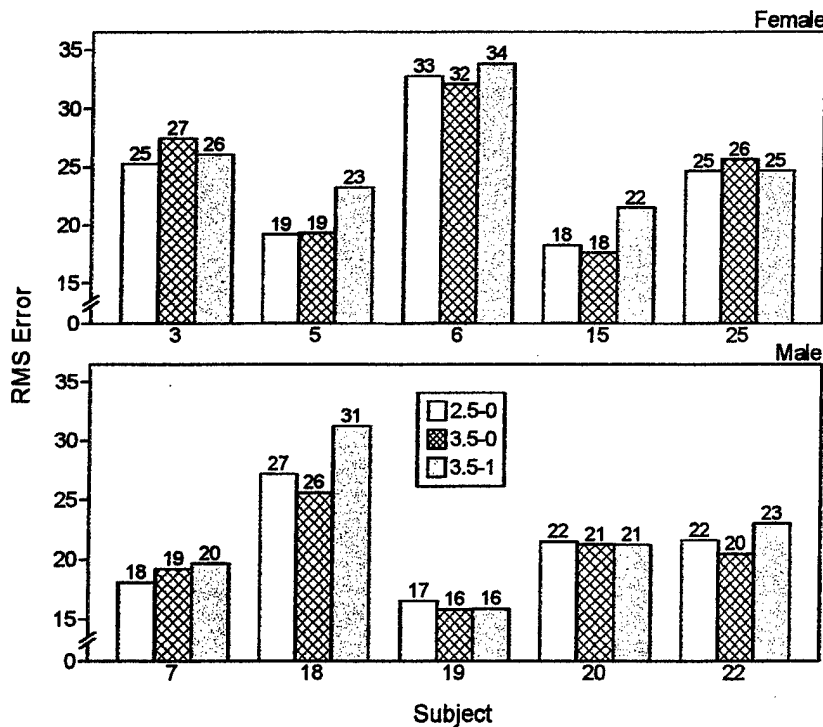


Figure 7. RMS Error at Gz = 6.5 averaged across task for each subject. Bar style represents helmet condition.

DISCUSSION

The main objective of this study was to compare helmet pointing performance between males and females under the G-environments examined herein. Additional factors were included in the study, such as helmet weight, CG, and task (simple or complex) to answer additional helmet and acceleration performance issues. All subjects participating in the experiment were able, without great difficulties, to perform all the required tasks under G. There were no incidents of G-induced physiological sequelae or loss of consciousness.

The study showed no significant difference in tracking task performance under Gz between females and males. Males, on average, performed better by 17%. When examining individual means, the tracking performance of the genders was similar, however, one of the five females was a relatively poor tracker while one of the five males was a relatively good tracker, accounting for much of the gender difference. Whether these tracking differences among subjects is related to their neck muscle activity will be examined in future analyses.

As expected, all subjects had more accurate tracking performance at 1.4 Gz. This stresses the fact that there is an inverse relationship between performance and the G-amplitude. When this stress is added to the actual flying task, it can further diminish performance.

Means followed trends where increasing helmet weight or a change in the CG resulted in poorer tracking performance, however, the mean differences were very small compared to the effects of task and Gz. The average weight of the HGU-55P flight helmet is 2.5 lbs. Adding 1 lb. of weight plus changing the CG of this added weight had little effect on performance. This added weight might have resulted in a big performance difference if a different pointing task or a multiple task (e.g., the dual task of pointing and communication) were used. It was determined early on, however, that the subjects had great difficulty in keeping their heads erect and pointing when more than 1 lb. of weight was added to the helmet at an extended position near the helmet brow.

Further research on the topic of helmet-mounted systems and performance in the high-G environment should include more operationally relevant tasks (e.g., dropping bombs, laser-guided munitions) for longer durations and at higher G-levels.

CONCLUSIONS

In this experiment, with the helmet aiming tracking task described and with the weights, CG, and G-levels described, there was not a significant difference in helmet pointing performance between males and females. Neither the addition of 1 lb. of weight near the CG of the standard HGU-55P helmet or moving half the pound to a position near the helmet brow pad had much effect on the helmet aiming and pointing task. There was a significant difference in helmet pointing performance between simple and complex tasks.

REFERENCES

1. Albery, W.B., Ten Eyck, R.P., Wolfe, M. Female exposure to high G: echocardiographic evaluation for chronic changes in cardiac function. *Aviat. Space Environ. Med.*, 1998; 69:857-61.
2. Albery, W.B. Echocardiographic evaluation of female centrifuge subjects for chronic changes in cardiac function. *Aviat. Space Environ. Med.*, 1999; 70:561-4.
3. Benjamin, C.R., Hearon, C.M. Urinary continence in women during centerfuge exposure to high + Gz. *Aviat. Space Environ. Med.*, 2000; 71:131-6.
4. Bulbulian, R., Crisman, R.P., Thomas, M.L., Meyer, L.G. The effects of strength training and centrifuge exposure on +G tolerance. *Aviat. Space Environ. Med.*, 1994; 65:1097-104.
5. Burton, R.R. G-induced Loss of Consciousness: definition, history, and current status. *Aviat. Space Environ. Med.*, 1988; 59:2-5.
6. Chelette, T.L. The effect of menstrual phase and oral contraceptives on female adaptation and performance at high G. U.S. Army Medical Research and Material Command Report, July 1997.
7. Chelette, T.L., Albery, W.B., Esken, R.L., Tripp, L.D. Individual performance during high-G simulated flight after 24 hours of sleeplessness. *Aviat. Space Environ. Med.*, 1998; 69:862-8.
8. Chelette, T.L., McCloskey, K.A. Females in the Dynamic Acceleration Environment, *SAFE Journal*, 1995; 25(1) 3-51.
9. Convertino, V.A., Tripp, L.D., Ludwig, D.A., Duff, J., Chelette, T.L. Female exposure to high G: chronic adaptations of cardiovascular functions. *Aviat. Space Environ. Med.*, 1998; 69(9): 875-82.
10. DeHart, R.L. *Fundamentals of Aerospace Medicine*, 2nd Edition, Baltimore: Williams & Wilkins; 1996.
11. Fisher, M.D., Wiegman, J.F., Bauer, D.H. Female tolerance to sustained acceleration- a retrospective study. *SAFE*, 1992; 22(2): 31-5.
12. Forster, E.M., Whinnery, J.E. Recovery from +Gz-induced Loss of Consciousness: Physiologic Considerations. *Aviat. Space Environ. Med.*, 1988; 59(5): 517-22.
13. Gillingham, K.K. G-tolerance standards for aircrew training and selection. *Aviat. Space Environ. Med.*, 1987; 58(10): 1024-6.

14. Gillingham, K.K., Schade, C.M., Jackson, W.G., Gilstrap, L.C. Women's G Tolerance. *Aviat. Space Environ. Med.*, 1986; 57(7): 650-4.
15. Heaps, C.L., Fischer, M.D., Hill, R.C. Female acceleration tolerance: effects of menstrual state and physical condition. *Aviat. Space Environ. Med.*, 1997; 68(6): 525-30.
16. Lebrun, C.M., McKenzie, D.C., Prior, J.C., Taunton, J.E. Effects of menstrual cycle phase on athletic performance. *Med. Sci. Sports Exerc.*, 1995; 27(3): 437-44.
17. Lyons, T.J. Women in the cockpit - aeromedical evaluation. *Aviat. Space Environ. Med.*, 1992; 63:809-18.
18. McCloskey, K., Esken, R.L., Scarborough, E.L. Methods for Test and Evaluation of Night Vision Goggle Integrated Helmets, proceedings of the Human Factors Society, 1991.
19. Popper, S.E., McCloskey, K.A. Individual differences and subgroups within populations: the shopping bag approach, *Aviat. Space Environ. Med.*, 1993; 64:74.
20. Tripp, L.D., Chelette, T.L., Savul, S., Widman, R.A. Female exposure to high G: effects of simulated combat sorties on cerebral and arterial O₂ saturation. *Aviat. Space Environ. Med.*, 1998; 69(9): 869-74.
21. White, D.D., Gotshall, R.W. Women have lower tolerance to lower body negative pressure compared to men. *J of Applied Physiology*, 1996; 80:1138-43.